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SPACE PRODUCT DEVELOPMENT: BRINGING THE BENEFITS OF SPACE DOWN TO EARTH

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Abstract

In fulfilling the National Aeronautics and Space Administration's (NASA) responsibility to encourage the fullest commercial use of space the Space Product Development (SPD) Program, within the Microgravity Research Program Office (MRPO) located at the Marshall Space Flight Center (MSFC) in Huntsville, Alabama, is managing an organization of Commercial Space Centers (CSC's) that have successfully employed methods for encouraging private industries to exploit the benefits of space-based research. Unique research opportunities of the space environment are being made available to private industry in an effort to develop new, competitive products; create jobs; and enhance the country's quality of life. Over 200 commercial research activities have been conducted in space by the CSC's and their industrial partners during the last several years. The success of this research is evidenced by the increasing amount of industrial participation in commercial microgravity research and the potential products nearing marketability.
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Introduction

As part of NASA's Human Exploration and Development of Space Enterprise, the MRPO is leading the nation in furthering the development of the space frontier by investigating the physical, chemical, and biological effects exposed by research conducted in the microgravity environment of space. Microgravity research is a natural extension of traditional Earth-based laboratory research in which a new class of unique experiments can be performed using the benefits of the stable, long-duration low-gravity environments provided by NASA's research platforms. Just as on Earth, both scientific and commercial interests are performing similar space research in many of the same disciplines, but with very distinct goals and objectives.

The microgravity environment gives researchers a unique opportunity to study the fundamental states of matter—solids, liquids and gasses—and the forces that affect them. In microgravity, researchers can isolate and study the influence of gravity on physical processes, as well as phenomena which are normally masked by gravity and thus difficult, if not impossible, to study on Earth. Using space as a laboratory for conducting research is an extremely challenging endeavor, with tremendous scientific, educational, societal, and commercial value.

In 1996, NASA designated MSFC as the Agency's Lead Center for Microgravity Research. The MRPO at MSFC was created to consolidate and integrate programmatic management of all NASA's microgravity activities, both scientific and commercial. Microgravity activities are spread across five NASA Centers, with government, academic, and industrial partners in over 40 states and foreign countries.

The purpose of the microgravity science program is to use the microgravity environment of space as a tool to advance knowledge; to explore the nature of physical phenomena, contributing to progress in science and technology on Earth; and to study the role of gravity in technological processes, building a scientific foundation for understanding the consequences of gravitational environments beyond Earth's boundaries. Scientific disciplines supported by the program include biotechnology, combustion science, fluid physics, fundamental physics, and materials science. In many cases, the research conducted by the microgravity science program for the sake of increasing knowledge is, in turn, the starting point for the product-oriented research conducted by the commercial research program.

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The purpose of the commercial research program is to use the unique attributes of space to conduct industry-driven research in which materials or knowledge developed in space can be used on Earth for the development or improvement of a commercial product or service. Commercial space research has the potential to create new or improved products, create jobs, give U.S. industry competitive advantages, and improve the quality of life on Earth. Managed by the MRPO's SPD Program, NASA's commercial research program is primarily implemented through CSC's. Each CSC is a consortium of academia, industry, and government that is usually located and managed at a university. The CSC's pursue product-oriented research in disciplines such as biotechnology, biomedicine, agriculture, and materials processing. NASA's role in this partnership is to provide leadership and direction for the integrated program and to provide the flight opportunities that are essential to the success of these efforts.

The CSC's play a unique and integral role in allowing private industry to enter into space research. CSC's furnish infrastructure that provides an inexpensive and effective way to design, develop, and operate experiment hardware in space. CSC's also initiate industry involvement, first by identifying and investigating areas of potential commercial promise, and second by marketing these potential research opportunities to private companies. As participants, the commercial affiliates contribute to the research effort with money, technical expertise, sample materials, personnel, ground facilities, and hardware.

NASA's success at encouraging the commercial use of space is demonstrated by the many commercial partners, potential products nearing marketability, and the increasing industry contributions to microgravity research. The SPD Program currently supports 13 organizations, including 9 CSC's, 3 NASA Field Centers, and 1 independent developer. Currently, the commercial payload developers have a combined total of 264 affiliates, including 183 industrial, 53 academic, 18 government, and 10 other partners. To date, the CSC's commercial partners have invested over $430 million in commercial space research. Space Shuttle missions, the Russian *Mir* space station, and sounding rocket flights have supported over 200 commercial research activities.

Potential Products Enabled From Space Research

Although there are many potential products being pursued within the commercial microgravity research program, selected areas of research and potential products have been chosen to exemplify the commercial researchers' roles and their achievements. While there is diversity in the range of potential products, areas of research, and industrial partners: the role of the CSC is consistent: increase industrial interest in performing space-based research by establishing the initial commercial potential and providing the necessary means to conduct the research.

Wisconsin Center for Space Automation and Robotics

The Wisconsin Center for Space Automation and Robotics (WCSAR), a NASA CSC located in Madison, Wisconsin, is pursuing agricultural research in space. In investigating the commercial opportunities within space-based agricultural research, WCSAR has developed the experiment hardware and scientific understanding necessary to provide a viable business opportunity for agricultural industries. WCSAR's establishment of this infrastructure has resulted in the development of private industry interest in at least two potential product areas. In addition to the potential products targeted by their research, a number of spin-off products have also resulted from the development of the space flight experiment hardware.

WCSAR and its industrial partners are exploring the effects of low gravity on the gene-transfer process used in the genetic engineering of plants. In the low gravity environment of space, the transfer of genetic information from one kind of plant cell to another is enhanced due to the lack of gravity-induced buoyancy and convection effects. This enhanced gene transfer in space could assist in the transfer of commercially valuable genetic information from one plant material to another. Microgravity-enhanced genetic plant engineering could lead to many improved or new agricultural products. For example, soybeans used for food production could be given more appetizing tastes and textures, or pest-resistant characteristics of one plant could be transferred to major crops like cotton or corn.

Once the space-produced transgenic materials have been incorporated into a terrestrial breeding program, 5 to 7 years of breeding and testing may be required for a plant variety to reach the market. Large economic gains result from the development of a new crop variety. Soybeans, the first plant targeted by WCSAR for transgenic improvements, represents an industry of more than $14 billion per year involving approximately 381,000 farms in 29 states. Thus product improvement which results in even a 1% increase in market share warrants significant industrial interest. Other agricultural food products have similar billion-dollar markets, any of which could potentially justify industrial investment.

Another area of plant-growth research indicates that plant cell metabolism is significantly altered in low gravity. The lack of gravity alters the chemical "messages" sent within the plant cells, causing them to behave differently than on Earth. Researchers at WCSAR believe that this altered behavior could be used to increase and enhance the production of specific natural products. Since some of these products are valuable even in very small amounts, the cultivation of certain plants in space might actually be commercially practical.

The $500 billion per year food market depends heavily upon natural plant products for flavoring. These products, which provide much of the flavoring and aroma in fruits and vegetables, will become more important as consumers place greater emphasis on foods which are highly nutritious but which may not be naturally flavorful.

However, before any hopes of market success can be fulfilled, research into transgenic plant materials and specific natural plant products will require suitable experimental facilities in space and reliable knowledge on how to use them. To meet this need, WCSAR has developed and flown the ASTROCULTURE™ plant chamber, which not only enabled the growth of plants in space during its development but, more importantly, validated the principles and subsystems necessary to successfully grow plants in space. Now that the initial research and development of plant-growth chambers in space is complete, WCSAR is preparing for the *International Space Station* (*ISS*) era by building the Commercial Plant Biotechnology Facility (CPBF), which will be more suited for conducting a larger scale of plant-growth research needed by commercial users.

Initial plant research in space has identified the potential for significant advances in the agriculture industry. WCSAR's development and demonstration of the ASTROCULTURE™ plant-growth hardware, along with the promise of a suitable space station research facility, has provided the means for industry to investigate those potential advances.

In addition to these targeted areas of research, other products have resulted from WCSAR's investigations and hardware development. These spin-off products include specialized, terrestrial, plant-growth chambers; educational products; and a new lighting device that may be used to treat cancer patients.

On the market since fall 1996, the CERES 2010™ plant-growth chamber provides a controlled terrestrial plant-growth environment suitable for supporting laboratory research in the pharmaceutical, food, and other agriculture-related industries. Based on the subsystems developed for the ASTROCULTURE™ and the CPBF hardware, the CERES 2010™ chamber uses high-intensity light emitting diodes (LED) lighting, porous-tube water and nutrient delivery, porous-tube humidity control, and solid state temperature control. The CERES 2010™ also provides for the control of atmospheric gas composition, notably the removal of ethylene, without consuming materials.

Another WCSAR industrial partner is readying two educational products for market. SpaceSpuds™ and Star Chamber™ evolved from WCSAR's potato-growing experiment during the STS–73 Space Shuttle mission in the fall of 1995. SpaceSpuds™ is a kit intended as a science education tool for sixth graders to high school seniors. It contains two potato stem cuttings and a booklet explaining the basic science of tuberization. Star Chamber™ is a simple, inexpensive plant growing chamber that may be used for a variety of simple plant science experiments, including tuberization using Space Spuds™. Space Spuds™ is currently ready for market, and a prototype Star Chamber™ has been built and successfully tested. The industry partner plans to launch the product during the 1997–98 school year. Combined annual sales of the two products are expected to exceed 17,000 units.

Special lighting technology developed for the ASTROCULTURE™ experiments may soon be on the market to help treat cancer. A cancer treatment technique called Photodynamic Therapy is based on the use of light-sensitive, tumor-fighting drugs activated by LED's developed for the ASTROCULTURE™ hardware. A light-activated drug is administered to a cancer patient and the drug accumulates in the tumor tissue. A specific wavelength of light is then used to activate the drug to destroy the tumor, leaving healthy tissues virtually untouched. The ASTROCULTURE™-developed LED's form the tip of a new probe that is used to irradiate the drug-laden tissue. Lasers have been used in the past, but are expensive, difficult to use, tend to overheat, and if the light is not properly dispersed, its efficacy is reduced. Compared to laser systems, the new LED system provides more consistent irradiation, costs much less, is portable, and remains cool to the touch even though it is three times as bright as the Sun in its spectral range. An LED-based photodynamic therapy probe is expected to be on the market very soon after clinical trials are completed.

Auburn University Solidification Design Center

The Auburn University Solidification Design Center, a NASA CSC located in Alabama, is researching and collecting information about the behavior of molten materials used in the casting industry. Data on the thermophysical and metallurgical properties of metals will be an important competitive edge for companies designing and producing metal castings.

Over 80% of all foundries in the United States are small businesses that employ less than 100 people. In order to remain competitive in a world market, foundries are using CAD/CAM technology to model their casting solidification process. Accurate models of the process and materials greatly improve casting quality while lowering costs, because the improved models allow the design engineers to better understand and control their manufacturing process. However, in order to more accurately and precisely model the behavior of molten and solidifying materials, engineers need reliable data about the materials' properties, specifically thermophysical properties.

In measuring thermophysical properties, standard techniques using terrestrial furnaces work well for most materials. However, on Earth, many important advanced materials react with and become contaminated from the actual containers required to hold them while raising the material to a molten condition. In the weightlessness of space, however, these materials can be melted without any container and their properties measured very accurately.

Among those materials which have reactive melts are the nickel and titanium alloys used in aerospace, chemical processing, and medical implant applications; magnesium alloys and high-temperature aluminide alloys used in the aerospace and automotive industries; and alloys of rare-earth metals used for permanent magnet applications. In a more tangible sense, turbine blades for jet engines and power generation will become more cost-effective and reliable as their manufacturing processes are improved.

Measuring the properties of these materials in space requires the establishment of experiment protocols and the development of specialized instrumentation. Auburn University not only develops the experiment protocols, but is also developing the furnace and measuring instruments necessary to conduct this research on the *ISS*. The Vulcan hardware being designed by Auburn University will provide a furnace suitable for containerless processing of commercially interesting materials. All the necessary instruments for studying and measuring the thermophysical data will be incorporated, as well.

Significant industrial resources have already been invested in this research. Financial commitments are expected to increase as project milestones are reached and space-based capabilities are demonstrated. Seven commercial partners are already collaborating with Auburn University, and market impact would be felt quite quickly since these companies are ready to utilize the space-based data into their process models. Domestically, metal casting represents an annual $25 billion industry with an estimated scrap rate of 10%. Commercial interest from the industry is justified even by fractional impacts in improving the process yields above 90%.

BioServe Space Technologies

Located at the University of Colorado in Boulder, Colorado, BioServe Space Technologies is a NASA CSC that is sponsoring a wide variety of biotechnology research ranging from agriculture to pharmaceuticals. BioServe has conducted extensive research which has identified potential products in different biotechnology, pharmaceutical, and biomedical disciplines. While the initial research and potential products are unique to each area of research, BioServe has developed a set of generic space-flight hardware that can be shared by multiple life science disciplines in conducting their experiments. The combination of identifying significant commercial potential and providing an established means to perform the research has allowed BioServe to affiliate with over 75 research partners, 60 of which are from non-aerospace industry.

Early research by BioServe demonstrated that plants growing in the weightless environment of space produce less lignin, their main structural component. Being able to manipulate the amount of lignin in trees is of great interest to Georgia Pacific, a BioServe commercial partner who is hoping to improve production efficiencies, extraction percentages, and product quality by gaining an understanding of basic plant processes that appears achievable only from space-based research. Successful product research in this area could result in low-lignin trees that would make paper production more environmentally friendly and, thus, less expensive. The current process for making paper uses an expensive, chemical-based process to remove lignin from trees. Successful research might also lead to the ability to increase lignin in trees, allowing the lumber industry to produce stronger wood products.

The current market for forest products in the United States is measured in tens of billions of dollars. The size of this market could easily translate a relatively small research success into significant financial returns.

Key to getting Georgia Pacific's interest was BioServe's initial research which used CSC-developed flight hardware. BioServe took the initiative to investigate the possibilities in this area of space-based plant research and advanced it to the point of commercial interest. At the same time, BioServe spent considerable effort understanding the NASA process for designing, integrating, and operating space flight hardware. ASTRO-PGBA, hardware developed in a collaboration between BioServe and WCSAR, provided the high-quality means to study plant lignification and metabolism in space. BioServe plans to continue this research on the forthcoming *ISS* using the WCSAR-developed CPBF.

In addition to the lumber and paper industries, BioServe has identified a way that plant research in space could benefit the plant-produced pharmaceutical industry. Research at BioServe has shown that since plants in space are not spending as much metabolic energy producing lignin, they may be able to produce more secondary metabolites. These secondary compounds are used by the pharmaceutical industry to produce about $50 billion worth of drugs annually. The potential to enhance the production of plant-produced drugs has motivated Bristol-Meyers Squibb and other companies to become BioServe commercial partners. BioServe's goals in this area of commercial research are to verify the hypothesis that pharmaceutical production is enhanced in space, determine the mechanisms involved, and use this information to develop methods to manipulate pharmaceutical production in terrestrial plants.

In another area of biotechnology research, BioServe is pioneering a way to use the physiological effects of space flight as a drug-testing model for diseases that attack the immune system, reduce bone mass, and cause muscle atrophy. The unique weightless environment of space causes numerous physiological changes that are similar to diseases that occur on Earth. However, the changes in space seem to occur more rapidly. For example, measurable decreases in bone mass occur in space in less than 2 weeks, while a comparable amount of bone loss on Earth due to disease would take months or years. This accelerated model of bone-weakening diseases can be used to test the effectiveness of drugs that fight osteoporosis, shortening the development time for drug companies.

Chiron, another BioServe partner, has used the physiological effects of space to advance the development of their product Proleukin, a drug currently on the market for treating metastatic renal cell cancer, which has great promise in treating other diseases and disorders. Proleukin is expected to be an effective treatment for other forms of cancer as well as immune disorders, influenza, and opportunistic infections that afflict Acquired Immune Deficiency Syndrome (AIDS) patients. Chiron and BioServe have used space-induced, immune-system depression in mice to test the effectiveness of Proleukin, resulting in a shortened testing schedule for the drug. Chiron is currently in Phase II clinical trials for Proleukin as a complementary treatment for AIDS and for malignant melanoma. With continued success, the drug could be available to patients within a few years.

BioServe has also furthered research and commercial interest in the effects of space on microorganisms which produce antibiotics. Since 1990, BioServe has been developing hardware and conducting research necessary to quantify the effects of space on the behavior of microorganisms. Their experiments have shown that the growth of microorganisms is enhanced in the gravity-free environment of space. The lack of sedimentation and convective flows increases the growth of microorganisms, allowing them to produce much more secondary compounds such as antibiotics. One experiment on STS-77 in 1996, showed a 200% increase in the production of the antibiotic monorden. Such promising results maintain the enthusiasm of commercial affiliates such as Bristol-Meyers Squibb while research continues toward applying space-gained knowledge to ground-based production. Similar to the other potential markets being researched, the global production of antibiotics is a $20 billion industry every year.

The commercially-advantageous space-research opportunities are being provided to industry through the unique partnerships developed by the NASA CSC's. As in most cases, BioServe provided the initial research that demonstrated to industry the potential for significant improvements in their products. Also, as in the case of microorganism research, BioServe developed the experiment, space-flight hardware necessary to conduct the research. The Commercial Generic Bioprocessing Apparatus (CGBA), which was designed, built, and operated by BioServe, provides the means to study microorganisms and pursue many other areas of research in space. Although CGBA will be used initially for research on the *ISS*, it will be replaced by BioServe's Generic Bioprocessing Rack in 2001. This facility is designed to exploit the unique capabilities of long-duration microgravity research on a space station.

Center for Macromolecular Crystallography

The Center for Macromolecular Crystallography (CMC), a NASA CSC located at the University of Alabama at Birmingham, is using the low-gravity environment of space to grow protein crystals for use in drug design. The CMC has attempted to crystallize hundreds of proteins in space, each with a potential product. Despite relatively good research success, the long time required to get a pharmaceutical to market has allowed only a few potential products to reach clinical trials and the final pre-market stages of development.

Very often in drug research a particular protein molecule is identified as the key to the propagation or function of a particular disease, virus, or other illnesses. Drugs are then designed to attach to the protein and inhibit its function. To design the drug, researchers need detailed information about the protein's three-dimensional structure. This structural information is commonly obtained by analyzing a crystal of the protein using a technique called x-ray diffraction. The quality of x-ray diffraction results depends largely on the quality and size of the protein crystal. In many instances, protein crystals grown in space are much larger and have fewer defects than those grown on Earth. These larger and more perfect crystals provide much better x-ray diffraction data, which are used to design more effective drugs.

Although hundreds of potential products could result from protein crystal growth research in space, many years of effort are required to get a new medicine on the market. Obtaining a sufficient number of high-quality space grown crystals can take from 1 to 5 years. After that, it can take 2 years for x-ray diffraction analysis and determination of the protein structure. Once the structure is determined, designing and synthesizing a drug takes 2 to 4 years and 5 to 10 years for human clinical testing. Finally, there is a 1 to 2 year Food and Drug Administration approval process before the product can be marketed. Realizing that bringing a new drug to the market can easily take 15 years or more, it is not surprising that only a few potential products are reaching the later stages of this process since the CMC began their space-based research and structure-based drug design program in 1985.

One product that is working toward market readiness is a treatment for influenza. Neuraminidase is a protein crucial to the flu's ability to infect the body. The CMC was able to grow neuraminidase crystals in space on STS–73. The resulting structural data have led to improvements in a neuraminidase inhibitor that is set to begin clinical trials in early 1998.

Another potential product in preclinical trials is an inhibitor to Factor D, a naturally occurring protein that causes problems for heart disease and stroke victims and inflammation in heart-surgery patients. Using crystals of Factor D grown on STS–50, x-ray diffraction analysis provided researchers enough structural information to design a lead compound for a drug that inhibits the function of Factor D. The Factor D inhibitor is expected to be in clinical trials in the near future as a treatment for open-heart surgery patients and stroke victims.

The CMC is also studying insulin crystals in an attempt to help a commercial partner improve the time-release properties of the diabetes-fighting drug. Researchers believe that if they can find a non-toxic way to bind insulin molecules together, they will dissolve slower and last longer in the bloodstream, thereby requiring less-frequent injections for diabetes patients. Specific details of the research are proprietary, but results are expected to have a wide range of impacts in insulin therapy.

The CMC has used their partnership with NASA to grow high quality protein crystals in space. These valuable, improved crystals are critical to a broader area of ground-based research known as structure-based drug design. These improved protein crystals, which are the source of valuable x-ray diffraction data, have been grown by the CMC since 1985, using experiment hardware specially design for space flight. Over the years, as improvements to the crystal-growth process have been discovered, experiment hardware has been upgraded accordingly by the CMC. As the CMC takes the protein crystal growth research to the *ISS*, it will be using a new generation of advanced crystal growth hardware. The CMC also plans to pursue an on-orbit capability for performing x-ray diffraction analysis on the *ISS*. On-orbit analysis would greatly reduce the time necessary to obtain research results and reduce the expensive amount of logistics necessary to return samples for analysis on the ground.

The CMC's success in using space to grow protein crystals has attracted many major pharmaceutical companies as research partners. Commercial affiliates include Bristol Meyers Squibb, DuPont Merck Pharmaceuticals, Eli Lilly, Johnson & Johnson, Parke-Davis, Schering-Plough, Upjohn, and many more major drug manufacturers.

The potential economic impact to the $200 billion annual pharmaceutical market could easily be in the hundreds of millions of dollars. The likelihood of research success is validated by the large number of major drug companies already partnered with the CMC.

Marshall Space Flight Center

Researchers at MSFC are investigating materials known as aerogels in pursuit of commercial opportunities. MSFC scientists believe that studying the formation of aerogels in space could be the key to producing significantly better aerogels on the ground. The potential improvement in aerogel's transparency and insulating properties could lead to products such as windows that are more thermally efficient and wire insulation that could support future generations of high-speed computers.

Aerogels are the lightest known solid and are only three times heavier than air. Despite their lack of substance, aerogels are one of the best thermal insulators available. One inch of aerogel insulation, with an R-value of over 20, can shield a flower from the heat of a blowtorch. Along with being exceptional insulators, aerogels are transparent, making them candidate materials for high-insulation windows.

One limitation of aerogels made on Earth is the large size of pores on the surface. Large pores scatter light and give aerogels a blue tint. Aerogels grown in space, however, have shown a four-fold reduction in pore size, greatly enhancing the clarity. The objective is to understand how to use the data from the space aerogel to manufacture low pore-size aerogels on Earth.

Aerogels also have an extremely low dielectric constant, which makes them ideal candidates for a number of high-tech electronic applications such as high-speed computers. Over the next decade, the trend of increasing computing speed should put the state-of-the-art computer at around 24 GHz. One of the biggest technical challenges to 24 GHz computing is finding better ways to keep the interconnecting wires from shorting across the narrow dividing space that exists between the wires. Due to their extremely low dielectric constant, aerogels would make excellent wire insulation if they could withstand the manufacturing process.

Based on previous success in reducing aerogel pore size in space, researchers at MSFC believe that studying the formation of aerogels in microgravity could provide the knowledge needed to manipulate aerogel growth on Earth. A better knowledge of how aerogels form could be the key to increasing the strength and reducing the pore size of aerogels made on Earth.

Space Vacuum Epitaxy Center

Located at the University of Houston, the Space Vacuum Epitaxy Center (SVEC) is a CSC researching the growth of electronic materials in space for commercial applications. Unique from other SPD payload developers, SVEC is primarily using the ultra-high vacuum of space, not just microgravity, as a research tool.

The vacuum of space has been shown to be thousands of times better than terrestrial vacuum chambers. This extreme vacuum can be used to manufacture high-purity materials due to the lack of contaminants. In order to study the possibilities of using the ultra-vacuum in space to manufacture high-quality ultra-pure electronic materials. SVEC developed the Wake Shield Facility (WSF), an external, dish-shaped free-flying satellite that is deployed and retrieved by the Space Shuttle.

SVEC developed and flew the WSF to demonstrate the following: first, that an ultra-vacuum can be generated in low-Earth orbit; second, that improved, high-purity materials can be made using the space ultra-vacuum; and third, that industrial quantities of these materials can be made for commercial use on Earth. Completing three of four scheduled flights, the WSF has been able to grow thin films of semiconductor materials with extremely high purity. On the fourth WSF flight, 50 thin-film wafers will be grown, yielding an industrially useful amount of semiconductor material. Successful completion of the WSF flights will complete the proof-of-concept and set the stage for commercial acquisition of the WSF technology for manufacturing materials in space for use on Earth.

Ultra-vacuum processing is estimated to enhance the purity of different high-performance electronic materials from 10% to 500%. Devices that could use these high-purity materials include high-speed transistors, high-power microwave transistors, semiconductor lasers, high efficiency solar cells, and low noise transistors.

The market for microelectronics chips was approximately $80 billion in 1995. The WSF-produced materials will initially make the most impact on compound semiconductors, which account for $2 billion of the microelectronics chip market. A larger portion of the market will be affected as technologies are advanced using the high-purity electronic materials manufactured in space.

Summary

The research roles of WCSAR, BioServe, Auburn, CMC, MSFC, and SVEC are typical of those at other commercial payload development centers. The Consortium for Materials Development in Space, a CSC in Huntsville, Alabama, is pursuing research in biotechnology and the processing of electronic materials and metals. Instrumentation Technology Associates, a private company in Exton, Pennsylvania, is functioning as an independent commercial researcher of biotechnology and biomedicine. The Center for Commercial Applications of Combustion in Space is a newly-created CSC that is leveraging off of the science-based combustion research to provide data to commercial affiliates to improve combustion processes on Earth. The possibilities of improved zeolites are being investigated by the Center for Advanced Microgravity Materials Processing at Northeastern University in Boston, Massachusetts. Researchers at NASA's Johnson Space Center in Houston, Texas, have been very successful in developing microencapsulated drugs in space. NASA's Langley Research Center has provided the initial research to establish the commercial potential of growing polymer materials in space. The Center for Microgravity Automation Technology, a CSC located at the Environmental Research Institute of Michigan, is developing automated robotics for conducting research in space and is exploring the potential of using space in the entertainment and education industries.

Facilitating and encouraging the use of space for commercial products and services is a challenging endeavor for NASA. NASA's strengths, which have proven successful in making space flight a common occurrence, may not be the most suitable environment for the fast-paced commercial research required by business today. The CSC's and the other commercial payload developers are a unique and critically important resource to demonstrate to private industry the opportunities of using space to attain their business objectives. The CSC's success in increasing industrial interest in utilizing space not only allows NASA to share the cost of research, but also contributes to successfully meeting NASA's commitment to the Nation.

The potential benefits to the American people justify NASA's investment of resources. After the gap of time between space-based research and product development has been crossed, many of the current potential products stand to make significant impacts to the U.S. economy, create jobs and improve the quality of life on Earth.